Melt Stabilization of PbSnTe in a Magnetic Field

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PbSnTe is a semiconductor material with a compositional dependent energy bandgap adjustable from 0 ev (40% SnTe) to 6.4 ev (100% PbTe). A direct bandgap makes this material useful for both infrared lasers and detectors. The utilization of this and other materials in this general class is dependent on both the crystalline perfection of the material and the compositional homogeneity.

The objective of this research is to further elucidate gravity driven physical phenomena on the growth of this alloy compound semiconductor. This work, coupled with the past microgravity experiment in the Materials Experiment Apparatus (MEA) and the existing flight program to grow PbSnTe in the Advanced Automated Directional Solidification Furnace (AADSF) will form the most comprehensive set of space processing experiments performed to date.

The bulk growth of this material is interesting from a purely scientific point of view because the liquid is always solutally or thermally unstable. In a one-dimensional analysis with the growth axis parallel to the gravity vector, one of the pertinent fields (concentration or temperature) will be in a stable orientation and the other field will be in an unstable orientation. This double convective instability cannot be made stable by balancing thermal and solutal expansion in a high temperature gradient.

The first flight experiment, without magnetic fields, in this series was in the MEA furnace on Space Transportation System (STS) 61A in October 1985. It was shown that a high degree of convection was still apparent at the low growth rates used in this experiment. The convective instability may have been exacerbated because the crystal axis and the steady state gravity vectors were (estimated) perpendicular. Analysis of this flight sample served as a basis for continued ground-based research and the development of the subsequent flight experiments.

The application of a magnetic field to PbSnTe growth will dampen convective flow. The anticipated results, from numerical analysis, are that even in the MSFC superconductor magnetic furnace the growth will not become diffusion controlled but that the combination of magnetic field and low gravity environment will produce diffusion controlled growth.

Numerical modeling is an integral part of this endeavor. Computer simulation will aid in the design of the space experiment by its predictive capacity to optimize conditions for the growth. The key purposes of this portion of the study is to optimize the growth for both the Earth and the space experiments and obtain an estimate of the required magnetic field for low gravity growth.

The Earth-based experiments are relatively straight forward. Crystals are grown in a magnetic field. After growth they are evaluated for compositional uniformity and defect structure. The experimental parameters are ampoule dimensions, temperature gradient, and magnetic field strength and orientation. The solutal driving force can be varied by both changing the growth rate, the temperature gradient, ampoule size, and by changing the starting ratio of SnTe to PbTe. Numerical analysis helps select the experimental matrix.

Experimental results to date of 1 cm diameter crystals grown in a 80 °C/cm thermal gradient with growth rate as a parameter are consistent with a totally mixed liquid even with the 5T field. This result, for these conditions, was predicted by our numerical analysis.

The application of a steady-state magnetic field offers a practical means of suppressing natural convection due to both the steady and unsteady changes in the residual acceleration. When an axial magnetic field is imposed, its effect on the convection in the melt is to interfere with the radial velocity component. As shown by asymptotic analysis, the magnitude of the radial velocity decreases proportionally to the square of, the strength of the magnetic field. When the field is large enough, an almost uniaxial flow and hence the desired diffusion-dominant growth condition, may be obtained. Our numerical results suggest that magnetic damping on the convective flow in the melt is practically effective for micro-gravity crystal growth.